VOLUME 81 PAPER No. 858

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

DECEMBER, 1955

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

EDUCATION OF CIVIL ENGINEERS: NEED FOR RECONSIDERATION

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BOARD OF DIRECTION

(Discussion open until April 1, 1956)

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

FOREWORD

Following a recommendation in 1951 of the ECPD Committee on Adequacy and Standards of Engineering Education, the American Society for Engineering Education appointed in May, 1952, a Committee on Evaluation of Engineering Education. This committee issued a preliminary report in October, 1953, an interim report in June, 1954, and a final report which was published in the Journal of Engineering Education for September, 1955. In brief, the committee recommends increased emphasis on the basic sciences, the engineering sciences, and the humanistic and social studies, accompanied necessarily by a de-emphasis of engineering art and practice, and elimination of or reduction in time allotted to courses which have a high vocational or skill content.

The papers by L. E. Grinter (Proceedings Paper 858) and by Benjamin A. Whisler (Proceedings Paper 859) consider the implications of the Final Report as it concerns the education of civil engineers.

This paper was published at 2500 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N.Y.

EDUCATION OF CIVIL ENGINEERS: NEED FOR RECONSIDERATION

L. E. Grinter,[1] M. ASCE

The ASEE Committee on Evaluation of Engineering Education was appointed by President S. C. Hollister in May, 1952, following discussion by ECPD of the need for a thorough restudy of the objectives of engineering education. The charge to the committee was to determine what changes are needed now in engineering education 1) for it to keep pace with the rapid advances that are occurring in science and 2) to provide the next generation with engineering leaders having the capacity to apply new scientific discoveries in a creative manner. The final report covers the committee's studies over a three-year period during which more than two hundred educational reports from institutional committees on engineering education, from engineering societies, industrial organizations, and individuals were studied. This brief summary is intended to give civil engineers a better insight into the problems of engineering education. It is hoped that many practicing engineers will read the full text of the report.[2]

Objectives of Engineering Education

The objectives of engineering education are twofold and are related to the technical and social responsibilities of engineers. The technical goal is preparation for the performance of analysis and creative design, or of construction, production, or operation in which a full knowledge of the analysis and design of the structure, machine or process is called for. The Committee on Evaluation has concluded that the greatest curricular deficiency in achieving the technical goal of engineering education lies in inadequate preparation of engineers in basic science including mathematics, in engineering science and in the planned use of this science background in engineering analysis, in the study of engineering systems, and in preparation for creative design.

The second objective, the broad social goal of engineering education, includes the development of leadership, the inculcation of a deep sense of professional ethics, and the general education of the individual. In this area there

1. Dean of the Graduate School, Univ. of Florida, Gainesville, Fla., and Chairman, Committee on Evaluation of Engineering Education, and Past-President of the American Society for Engineering Education.
2. Report on Evaluation of Engineering Education, 1952-1955, published by the American Society for Engineering Education, June, 1955, Urbana, Ill. This investigation was sponsored financially by the American Society for Engineering Education, The Engineering Foundation, the Constituent Societies of the Engineers' Council for Professional Development, the General Electric Company, and the National Science Foundation. Available from Secretary's Office, American Society for Engineering Education, University of Illinois, Urbana, Illinois, Price 25 cents per copy or 12 cents in lots of 100 or more.

is less unanimity of educational opinion, but there is a clear consensus of industrial and other employers who consider the young engineer to be unnecessarily handicapped by inability to convey ideas to others in a clear, logical, and interesting manner using correct and concise oral or written language. There is wide agreement that technical competence alone is insufficient and that a reasonable fraction of the engineering curriculum must be directed toward achieving a liberal education for engineers.

Curricular Recommendations

The consideration of the curriculum takes an undue share of the original Report and will take an even larger place in this brief summary. Actually, the Report recognizes clearly that the competency of the faculty, its ideals, objectives and methods are far more significant than the curriculum because a truly distinguished faculty can mold any curriculum to its objectives. However, only a few faculties can exert such influence. The framework of the curriculum can maintain the reactionary influence of the past, not only into the present, but far into the future. Since the great increase in students that we see just over the horizon will soon make it necessary for engineering colleges to increase their faculties with many inexperienced teachers, the present seems a most appropriate time to consider whether curricula in civil engineering are designed in the best possible manner for producing the leaders that will be needed by the profession twenty-five years from now.

The great changes in physics and chemistry over the past thirty years and the equally great advances in engineering practice do not seem to have produced an equivalent counterpart in a reorganization of engineering curricula. A group of industrial advisers to the Committee has pointed out that the problems in production and manufacturing are now demanding greater and greater scientific background for engineers. As one example, emphasis was placed upon automation as a current problem of the machine designer. The need for such instruction is critical in certain industries, and several of these offer such courses to their personnel. If this is generally true, engineering education may be a decade late in giving emphasis to electronics in the curriculum of mechanical engineering. Civil engineering is also beginning to feel the influence of automation. Greater adaptability to rapidly changing conditions seems clearly needed in engineering education.

But fortunately, some things do not change. Whether we look a generation or a century ahead, reactions, stresses, and deflections will still occur, and they will have to be calculated. Electrical currents and fields will follow unchanging laws. Energy transformation, thermodynamics, and heat flow will be as important to the next generation of engineers as to the present one. Solids, fluids, and gases will continue to be handled, and their dynamics and chemical behavior will have to be understood. The special properties of materials as dependent upon their internal structure will be even more important to engineers a generation hence than they are today. These studies encompass the solid unshifting foundation of engineering science upon which the engineering curriculum can be built with assurance and conviction.

Based upon such considerations, the Committee on Evaluation of Engineering Education recommends less specialization in terms of extensive intradepartmental offerings and greater dependence upon basic science, engineering science, humanities, and social studies. Departmental sequences serve their primary purposes as opportunities to apply fundamental scientific knowledge to analysis, design, and the study of engineering systems. The committee

agrees with the basic concept expressed by industrial leaders that specific details of engineering practice change too fast to be of value for classroom study except as they may serve the high purpose of illuminating fundamental unchanging principles. If this criterion is applied rather forcefully by civil engineering faculties, it is felt that opportunity will be found within the usual time limits to increase basic studies in science and humanities as recommended in the report.

In particular, the committee sees the need for increased study of mathematics, physics, and chemistry. It sees mathematics through ordinary differential equations, an introduction to nuclear physics, and more attention to physical chemistry as normal requirements of modern curricula in engineering. Great emphasis is given to the importance of the instruction in engineering science and its proficient application to analysis and design in engineering. An engineering science by definition involves largely the study of basic scientific principles as related to and as interrelated through engineering problems and situations. The fields of engineering science are defined specifically in the report to include mechanics of solids (statics, dynamics, and strength of materials); fluid mechanics; thermodynamics; electrical theory (electrical circuits, fields, and electronics); transfer and rate mechanisms (heat, mass and momentum transfer); and the nature and properties of engineering materials. Of course, these six titles of the engineering sciences should be regarded as generic and broadly definitive rather than as representative of courses now being offered. It is recognized that other engineering sciences may be expected to develop and that, alternately, there may be some curricula for which sciences other than those listed must be chosen, for example, an earth science or a life science.

It is recommended that about a quarter of the engineering curriculum be devoted to the study of the engineering sciences and about an equal fraction to their application in a departmental sequence in engineering analysis, design, and engineering systems. Hence the organization of basic science, engineering science, and engineering analysis becomes an integrated sequential study of great importance.

Humanistic and Social Studies

Among the many comments from employers of engineers that have been received by the committee none has come with greater frequency or stronger conviction than that urging the importance to engineers of the arts of communication and of social understanding. There is a nearly universal consensus among employers that engineers suffer unduly from lack of capacity for clear, concise, and interesting exposition and that they are limited in their ultimate development by an inadequate understanding of the humanities and the social studies. Although this viewpoint is accepted as true, there remains some question whether increase of fixed requirements of humanistic and social courses for all engineering students will eliminate this weakness.

A decade ago, an ASEE Committee recommended that about one fifth of the curriculum be in humanistic and social studies, but even this concession has not proved sufficient. Rather than to establish an increased percentage of the curriculum beyond this widely accepted figure of 20 per cent, the committee has concluded that a minimum of one course per semester for seven or eight semesters plus a broad opportunity for students to elect additional humanistic and social courses would be preferable. For students with cultural interests, all electives might appropriately be chosen in the nontechnical field to produce

about the same background as that of a liberal arts student who chooses to major outside of the humanities or social studies.

The fields of the humanities and social sciences from which some courses must be selected include history, economics, and government wherein knowledge is essential to competence as a citizen; and literature, sociology, philosophy, and fine arts which afford means for broadening the engineer's intellectual outlook. In contrast, it is observed that many curricula list as humanistic or social courses such technical subjects as accounting, industrial psychology, investment economics, corporate organization, city management, or ROTC. The committee questions the value of such studies as a major contribution to liberal education and considers that they should be classified as non-engineering technical courses with appropriate additional time provided for humanistic and social studies.

An Experimental Curriculum with Scientific Orientation

Emphasis is placed upon the fact that experimentation rather than standardization is needed in curriculum development. However, in order to demonstrate that its ideas are practical, the committee has found it necessary to offer an experimental time distribution for the scientifically oriented curriculum that it recommends for consideration. (Table 1).

It will be noted that the fractions given do not total exactly 100 per cent. Hence it should be evident that the committee does not desire this suggested distribution of emphasis to be restrictive. There will be many reasons for variations among institutions and among departments of a single institution. Experimentation, however, is strongly encouraged.

TABLE 1. Experimental Time Distribution for Scientifically Oriented Curricula

	Fraction of Curriculum
Humanistic and social studies	about one fifth
Mathematics and basic science	about one quarter
Engineering science	about one quarter
Major departmental sequence of analysis, design, and engineering systems including necessary technological background	about one quarter
Choice of options or electives in a) humanistic-social, b) basic science, c) engineering science, d) research or thesis, e) engineering analysis and design, f) management	about one tenth

The committee's interest in this curriculum outline is centered in 1) the indication that the concept of a four-year scientifically oriented curriculum is practical in many fields of engineering, although it takes no position that four years or any other length of curriculum represents the supreme desideratum, 2) the fact that considerably more than the "common freshman year" might be arranged, if desired, as one result of scientific orientation of curricula, 3) that even with increased science background time may be provided for elective or option study to offer the student an opportunity to try his wings in

one or two directions. Such elective study can contribute to a stronger humanistic-social background for some engineers and a stronger science background for others, with resultant over-all strengthening of the profession of engineering.

Interest of a Profession in Its Education

I have appreciated the opportunity to review for you that part of the Report on Evaluation of Engineering Education dealing with engineering curricula. Since this Report was published by the American Society for Engineering Education in June, 1955, one might wonder why only a small fraction of the engineering societies have informed their members adequately concerning the recommendations of the most extensive study of engineering education since the Wickenden Report of 1930. Undoubtedly, the editors and the Secretaries of the Engineering Societies did not generally believe that their members would find time to read either the complete Report or a detailed summary thereof. Hence, they have restricted published statements to a brevity commensurate with the interest of their readers. However, I should like to mention that as an exception, ASME published a rather full resume of the Report in "Mechanical Engineering" for October, 1955.

The fact that there may not be a broad base of interest concerning engineering education among practitioners of engineering leads to the question whether engineering is yet a profession; or possibly organizational channelization within the profession produces this apparent, rather than real, lack of interest. We should keep in mind that an important characteristic of a profession is that it shall take a strong interest in its own education. Since this interest did not develop early in the history of engineering, it was necessary for a group of professors in 1896 to form the Society for the Promotion of Engineering Education which later became the American Society for Engineering Education. This society has been very active in the study of ways and means of improving engineering education, and as a past president of that society, I am very proud of its accomplishments. Since I can readily name a hundred civil engineering teachers, each of whom has contributed at least an entire year of his life to the work of ASEE, civil engineers have been well represented, but it is still unfortunate that very few practicing engineers have been involved personally. I see no real change that can take place in this situation as long as the main engineering societies and ASEE are not associated more closely.

Coordination Through ECPD

An association between professors and practicing engineers has been worked out through Engineers' Council for Professional Development, but one must report that this association is quite tenuous. The most effective work of ECPD by every measure has been the accrediting procedure for engineering curricula. However, the tradition behind this accreditation program is one of devoted service primarily of engineering educators. Theoretically, ASCE and the other engineering society members of ECPD appoint the lists of inspectors of engineering curricula. Practically, unless such appointments are pretested by a trial run where engineering educators are necessarily the judges, the whole accreditation structure could be destroyed in a few years. Experience has proved that very few practicing engineers either can give or will give the time and attention to accreditation inspections that engineering educators consider essential. Hence the work of accreditation has fallen

largely upon the shoulders of the educators themselves. Although I believe that the accreditation procedure of ECPD has been effective, it has not encouraged the entire engineering profession to develop the interest in engineering education that it should have.

Comparison with Medical Education

It is a common procedure for writers on engineering education to attempt to idealize the procedures of medical education as an example to the engineering profession. Actually, the points of similarity are more evident by their absence than by their presence. If engineering education followed the medical pattern, we would probably graduate about one-quarter as many engineers as at present because the requirements would be about as follows: First, the pre-engineer would take a liberal arts course for four years with due emphasis upon the humanities and social sciences and special emphasis upon the physical sciences. At least one-half of those who started would drop out for the usual variety of reasons. Then the student engineer would begin a four-year program divided about equally between basic and engineering science on the one hand, as taught by research professors, and on the other hand some two years of practical engineering courses taught by practicing engineers. After his eighth year, he would graduate as an engineer and would start a two-year apprenticeship at a nominal wage where he would work for one of the top-flight industrial organizations, for a consulting engineer, or for a government laboratory. During this two-year period he would receive several hours a day of direct contact with a master engineer whose methods he would study. At the end of the two-year apprenticeship when he had reached the age of 28 or 30, he would be expected to be able to accept responsible charge of any engineering job within his field of specialization.

Learning the Art of Engineering

The educational picture presented is so divorced from our concepts of engineering education and practice today as to appear fantastic. We know that freshmen engineering students are quite anxious to study engineering immediately and are not likely to progress rapidly in humanistic or social science courses that precede science and engineering studies. Their appreciation and progress in non-technical studies is better in the junior and senior years. We also know that the art of engineering must be learned on the job. Practical engineering work can not be experienced adequately in the classroom or laboratory. There is no opportunity for practical education in engineering within a college comparable to animal experimentation or cadaver dissection in medicine.

Medical schools fortunately are associated with hospitals where the most advanced medicine is practiced by the professors and observed by the students. The teaching of engineering art in college is synthetic and relatively unproductive except as it is used to illustrate and teach the principles of engineering science and design. Anyone may clarify this point by considering to what extent he himself applied engineering art learned in college during his first years of practical experience. Instead, I believe each person will conclude that he applied day by day the engineering art that he had observed others to be using successfully in practice. By this procedure, one accumulates over the years a storehouse of techniques, methods, tools, devices and concepts; in short a storehouse of engineering art, that is always available for use.

The Study of Engineering Science

Since engineering art can not be taught with real effectiveness in college, we should place the technological emphasis of the curriculum upon engineering science instead. This procedure has the merit that all knowledge of engineering science and the basic sciences upon which it depends is transferable from field to field. An understanding of dynamics, for example, is applicable to the determination of the wind stresses in tall buildings, towers or suspension bridges, to atomic blast effects upon structures, to the analysis of machine vibrations and to airplane frame design. If one understands fully the basic principles and necessary assumptions, applications may be made in many fields; and in addition, such knowledge does not become out of date. In contrast, a knowledge of the art of handling concrete from the mixer to the forms is useful only in the field of concrete construction, a small segment of civil engineering, and such knowledge of the art is also subject to rapid obsolescence as new techniques and devices are developed.

We have observed that the engineering science of the mechanics of solid bodies is transferable knowledge of permanent value for study by all student civil engineers while the art of concrete placement is better learned on the job by the limited number of graduates who happen to accept employment in that field of specialization. A similar parallel may be drawn between the broad usefulness of the engineering science of fluid flow and the relatively limited application of practical techniques for stream flow measurement. Unless the entire approach to engineering education should be revised more nearly along the lines of medical education, we have so little time for the study of engineering art that it can appropriately serve only as a tool for illuminating the principles of engineering science and engineering design and not as a basic approach for the transfer of engineering knowledge.

We come then to the conclusion that the objective of a modern curriculum in civil engineering, mechanical engineering, electrical engineering or any other field of engineering specialization is to teach engineering science and its application to design. Specialization at the undergraduate level, including many courses unique to civil engineering, is the topping on the cake, tasty and attractive and useful psychologically as a means of selling the main package. Specialization usually partakes rather heavily of engineering art and should therefore not be overdone, since, as we have seen, knowledge of engineering art is less transferable and much more subject to obsolescence than knowledge of basic science, engineering science and engineering design which we call the "fundamentals" of engineering education. Equally "fundamental," however, are English communication and certain non-technical studies.

The Non-Technical Side of Engineering

Finally, it is well to inquire whether any or all of the things that we have discussed are the most important in the education of an engineer. I have just read a long article on decision making by administrators in industry. An amazingly light emphasis was given to scientific, technical or economic knowledge even though some such factors are involved in decision making in nearly every instance. Instead, psychological, social and human factors including strong character and a developed sense of ethics seem to weight very heavily in the make-up of the successful administrator or decision-maker. And since a large percentage of engineers eventually enter the realm of administration, one can not feel comfortable about the lack of emphasis upon the humanities

and the social sciences that has been particularly characteristic of civil engineering curricula.

As a start, we must drop the confused thinking that has accepted technical non-engineering courses such as accounting, business or city management, cost analysis, marketing, finance, engineering economics or ROTC as adequate substitutes for humanistic and social courses. When engineering educators face the issue that humanistic and social courses may be of the same order of importance as engineering science in the curriculum of engineering and that engineering art is useful primarily for illustrating applications of engineering science, we will be able to improve engineering curricula and will graduate stronger potential engineers. Since we can no longer hope to meet the demand for numbers of graduates, it is toward quality of graduates that our engineering schools should now strive. The engineer must live his entire life among men. Unless we have given due attention to the education of the entire man, which means much more than the development of an able technologist, we may have failed both the engineer of the future and the World itself.

Graduate Study as Professional Education

The preceding remarks have applied largely to the undergraduate curriculum. In four or more years of undergraduate study, the college attempts to lay a foundation for the future development of a real understanding of engineering problems by its graduates. It does not expect to achieve through the undergraduate curriculum an adequate understanding of engineering science for the professional engineer. To achieve the appropriate status of a professional engineer, the engineering graduate has the choice of graduate study or of further self education. It appears to be the trend for most professions to require either the master's degree or its equivalent in formal study before professional recognition is awarded. In engineering, where only a fraction of the graduates appear to desire professional recognition, since attractive employment outside the professional field is readily available, there would be an obvious advantage in retaining the bachelor's degree in engineering as a normal termination for those who do not seek professional recognition while establishing the master's degree as the normal channel for those who intend to become professional engineers.

There is widespread belief in engineering education that this natural solution to the problem of professional recognition is already well advanced and that it will either attain informal acceptance or be formally adopted within the next generation. The requirement of the master's degree in engineering science or its equivalent in self education for professional recognition would do much to produce a true profession of engineering knit together by a common understanding of engineering science at a level commensurate with the demands that industry and government will place upon the new generation of engineers now passing through our colleges of engineering.

PROCEEDINGS PAPERS

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VOLUME 80 (1954)

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)c, 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)c, 569(SM), 570(SM), 571(SM), 572(SM)c, 573(SM)c, 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(BD).

VOLUME 81 (1955)

JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)c, 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)c, 596(HW), 597(HW), 598(HW)c, 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)c, 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)c, 622(IR), 623(IR), 624(HY)c, 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)c, 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)c, 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)c, 655(SA), 656(SM)c, 657(SM)c, 658(SM)c.

APRIL: 659(ST), 660(ST), 661(ST)c, 662(ST), 663(ST), 664(ST)c, 665(HY)c, 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)c, 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)c, 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)c, 700(PO), 701(ST)c.

JUNE: 702(HW), 703(HW), 704(HW)c, 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)c, 710(CP), 711(CP), 712(CP), 713(CP)c, 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)c, 719(HY)c, 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)c, 727(WW), 728(IR), 729(IR), 730(SU)c, 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)c, 749(SA), 750(SA), 751(SA), 752(SA)c, 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)c, 759(SM)c, 760(WW)c.

AUGUST: 761(BD), 762(ST), 763(ST), 764(ST), 765(ST)c, 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(EM), 773(SA), 774(EM), 775(EM), 776(EM)c, 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)c, 783(HW), 784(HW), 785(CP), 786(ST).

SEPTEMBER: 787(PO), 788(IR), 789(HY), 790(HY), 791(HY), 792(HY), 793(HY), 794(HY)c, 795(EM), 796(EM), 797(EM), 798(EM), 799(EM)c, 800(WW), 801(WW), 802(WW), 803(WW), 804(WW), 805(WW), 806(HY), 807(PO)c, 808(IR)c.

OCTOBER: 809(ST), 810(HW)c, 811(ST), 812(ST)c, 813(ST)c, 814(EM), 815(EM), 816(EM), 817(EM), 818(EM), 819(EM)c, 820(SA), 821(SA), 822(SA)c, 823(HW), 824(HW).

NOVEMBER: 825(ST), 826(HY), 827(ST), 828(ST), 829(ST), 830(ST), 831(ST)c, 832(CP), 833(CP), 834(CP), 835(CP)c, 836(HY), 837(HY), 838(HY), 839(HY), 840(HY), 841(HY)c.

DECEMBER: 842(SM), 843(SM)c, 844(SU), 845(SU)c, 846(SA), 847(SA), 848(SA)c, 849(ST)c, 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)c, 857(SU), 858(BD), 859(BD), 860(BD).

c. Discussion of several papers, grouped by Divisions.

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